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DEVELOPMENT OF TECHNIQUES AND HARDWARE FOR INSULATION WRAPPINGS OF CRYOGENIC CONTAINERS

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ABSTRACT

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During this reporting period most of the work was directed towards completing drawings for the fabrication and assembly of the NRC-2* Superinsulation system. A design for the purge bag was conceived. The calculations for determining the optimum number of NRC-2 layers resulted in a value of 54 layers to yield the minimum ratio of non-useful to useful weight.

Author

INTRODUCTION

This research project covers the design of a helium purged NRC-2 Superinsulation system for use on a NASA 105 in. diameter liquid hydrogen storage vessel. The provision of design drawings for the purge bag and rupture device is included as well as recommendations for methods of making temperature and pressure measurements within the insulation system.

DESCRIPTION OF WORK DONE

Optimization Calculation

The determination of the optimum number of layers of NRC-2 to be applied to the vessel was determined by differentiation of a weight ratio equation. The ratio of non-useful to useful remaining weight after a finite period of orbiting was used as the criterion. The ratio, R, is composed of several factors which are functions of n, the number of NRC-2 layers, as defined below:

* Trademark National Research Corporation

$$R = \frac{X(n) - Y(n) + Z(n)}{W(n)} \qquad (1)$$

In equation (1), $X(n)$ is the weight of NRC-2, $Y(n)$ is the stabilization effect when the insulation changes from ground hold to orbital equilibrium temperatures, $Z(n)$ is the cryogen boil-off weight lost during 30 days of orbit and $W(n)$ is the weight of cryogen remaining in the vessel after 30 days of orbit. The optimum value of n will be obtained when:

$$\frac{dR}{dn} = 0 \qquad (2)$$

The weight of NRC-2 applied to the vessel may be calculated as follows:

$$X = \frac{n}{550} (1.5\, A_c + 1.5\, A_s + 1.2 A_p) \qquad (3)$$

where A_c is the area of the cylindrical section of the vessel, A_s is the area of the spherical ends, A_p is the area of the penetrating battens, and the constants account for the shingling and overlaps of NRC-2 and the conversation of area into pounds of insulation.

The weight of the cryogen to produce temperature stabilization in the insulation may be estimated as:

$$Y = \frac{1}{h} \int_{T_g}^{T_o} \left[X(n) + P \right] C_p \; dT \qquad (4)$$

where h = Btu/lb H_2 boil-off, P is the weight of the purge bag, C_p is the specific heat of the layer at the temperature of the layer, T_o and T_g are the temperatures in orbit and at ground hold respectively.

The loss of cryogen due to boil-off is:

$$Z = \frac{720\ A}{h} \left[\frac{K}{n} + \frac{4.28 \times 10^{-3}\ n}{SL} \right] \quad (5)$$

in which A is the area of the vessel, K is the radiation heat transfer coefficient for NRC-2 normal to the surface (K = 5.31 Btu - layer/hr-ft^2), S is the spacing between the top edges of the battens, and L is the length of the overlap of each batten. The constant, 4.28×10^{-3}, which was developed in the Fourth Quarterly Report, is a calculated value in Btu/hr-layer for lateral conduction of NRC-2 between 37 and 426°R.

The weight of cryogen remaining in the vessel after 30 days in orbit, W, is determined by subtracting the boil-off from the initial full weight as follows:

$$W = \rho V - Z \quad (6)$$

where ρ is the density of the cryogen and V is the volume of the vessel.

The equation for R can then be consolidated as follows:

$$R = \frac{2.27\ n + 6130\ n^{-1}}{2050 - 1.11n - 6130\ n^{-1}} \quad (7)$$

This equation when differentiated and set equal to zero yields:

$$4.66\ n^2 - 14.2\ n - 12.600 = 0 \quad (8)$$

The solution of this quadratic equation is n = 54. With 54 layers of NRC-2, a maximum amount of cryogen may be orbited and stored for a minimum fractional proportion of non-useful weight. The latter includes not only the weight of the NRC-2, but also the cryogen lost during the storage period.

Batten Design

A major proportion of the time spent during this quarter was used to work out the detailed dimensioning and positioning of the NRC-2 battens. Actual physical measurements were made of a typical scroll to accurately determine its size. The results of this work are shown on the manufacturing drawings. The intent of the design is as follows:

(1) To install the NRC-2 layers as isothermally as possible with no holes to allow radiation heat leaks.

(2) To minimize the lateral heat flow at overlaps by making them as long as possible, consistent with vessel penetration spacing and available material widths.

(3) To design the insulation for minimum installation time, so that it can be removed with minimum damage and still be fixed in place to withstand high accelerations.

(4) To prevent any gas leakage from vessel welds or seals from being able to enter the multilayers and degrade the value of the NRC-2 Superinsulation and at the same time provide adequate passages for purge gas exit during ascent.

Since details of the piping from the vessel have not been provided, a general solution was indicated for later development by NASA.

Purge Bag Design

The concept for the purge bag release device as shown in Figs. 1 and 2 was developed and a study of materials for construction of the bag was continued.

A suitable material was required for making transition joints for the purge bag. The tubing which is used to pump out atmospheric air and then introduce helium must be tightly sealed to the bag material. Since moldings of silicone rubber are readily available and the estimated lowest temperature of the purge bag, 378°R, is above the lowest service temperature for silicone rubber, some simple tests were made to check the usefulness of the material.

One inch wide strips of silicone rubber 3/32 in. thick were attached to one in. wide strips of .001 in. Mylar with DuPont adhesive Nos. 46990 and 46960 (Details in NRC Notebook 2549). The overlap joint was one in. long. The samples were submerged in liquid nitrogen, one at a time, for one minute. They were then removed and quickly inserted in the jaws of an Instron testing machine and pulled to fracture. One 46960 sample fractured at 9 lb load, one 46960 sample broke at 8 lb load. The failures occurred at the junction of the Mylar and silicone rubber where the rubber strain was a maximum. The rubber curled and distorted when cooled in the liquid nitrogen although it remained strong. The weak link in the system was the adhesive. Eight to nine lb/in^2 adhesive strength was too low to be useful in the intended application. No further search was made to find a suitable adhesive and no further consideration was given to using silicone rubber moldings for the transition pieces.

In place of the rubber moldings, epoxy-fiberglass assemblies are recommended. The adhesive joint between the Mylar and epoxy-fiberglass composite can be made either with a polyester adhesive or with an epoxy. The former is much easier to work with and apply. Further description of the transition pieces and other joints in the purge bag will be shown in the drawings to be submitted.

Before arriving at the release device shown in Figs. 1 and 2, a method of releasing the gas by a controlled rupture of a taped joint was considered. These tests are reported for the record, but are not considered useful since a better method for purge bag release has been determined.

Some Schjeldahl GT-100 tape 1/2 x 1 (1/2 mil adhesive only, no backing) was heat sealed between two layers of 0.001 in. thick Mylar. The samples were submerged in liquid nitrogen and then rapidly inserted in an Instron test machine and pulled to failure. The peel strength was of the order of 2 lb.in with 1/2 mil adhesive, and 4 lb/in with 1 mil. A room temperature sample was not significatly different. One sample in which some GT-300 tape 1/2 x 1/2 x 3/4 in. wide (1/2 mil adhesive-1/2 mil Mylar) was applied to the Mylar and the adhesive stressed in shear (not as for peel strength) broke the tapes in tension. Making a purge bag with a peel type joint held with tape in tension would have provided a predictable, controllable release point, but lacked two features which were available in the system later conceived and shown in Figs. 1 and 2.

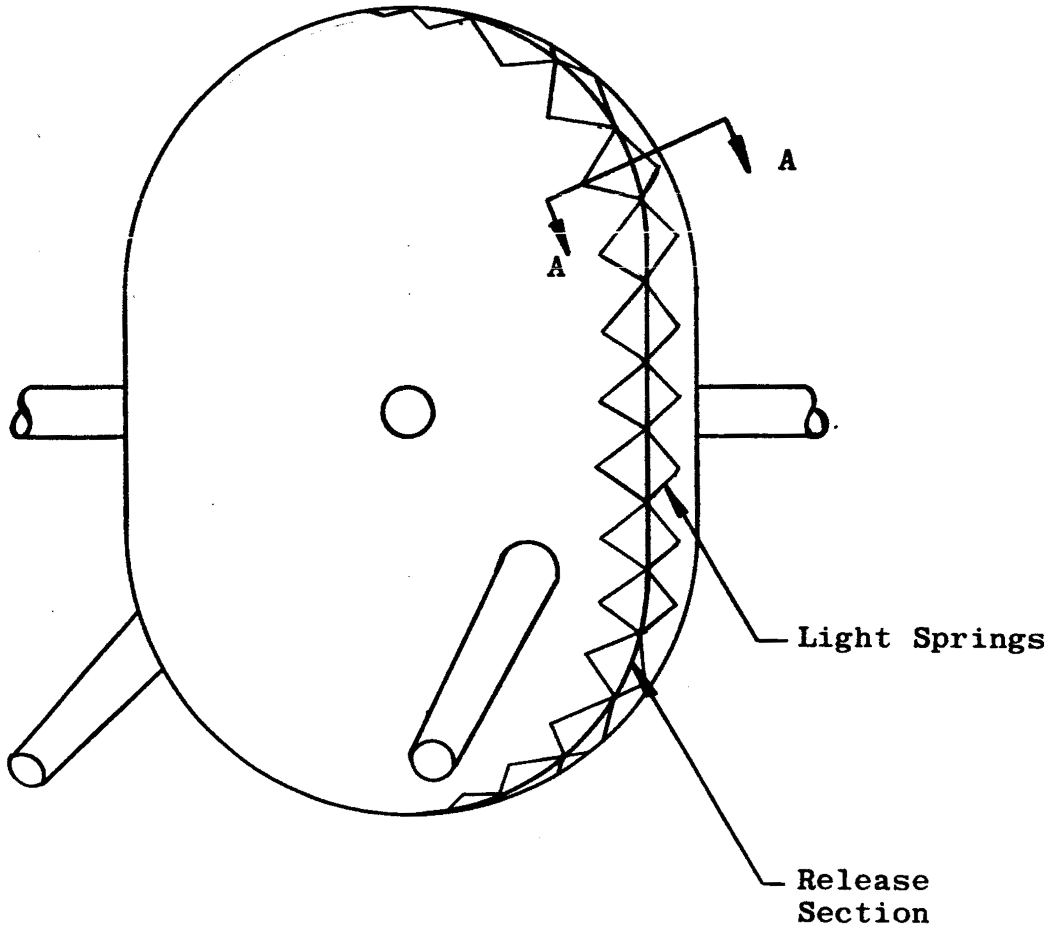
The first of these features which is inherent in the design shown in Fig. 2 is instability which causes the complete joint to release as soon as any one section releases. The second is a means of insuring that the opening will remain wide open even after the initial relatively high pressure gas is released. This is accomplished by means of the light weight, low-spring-rate extension springs shown in the illustration. These springs are in tension when the bag is purged with helium, but return to free length when the release device has operated thus holding the edges of the seal widely separated around the entire circumference of the vessel.

One other important aspect of the design is the selection of a sensing system which will provide for reliable operation of the purge bag release at the right time in spite of factors such as vibration and temperature. After considerable study of various possibilities, it appeared that a change in pressure due to the ascent of the vehicle would provide the most definite signal. At an elevation of approximately 1900 feet, the pressure changes 1 psi; a change which is greater than the fluctuation of normal atmospheric pressure.

At the pressure difference of 1 psi between the inside and outside of the bag, the bag material is subjected to tension of nearly 60 lb/in. To allow pressure differences significantly greater than this would necessitate a weight penalty for heavier bag material and cause unnecessarily high purge gas escape velocities. To attempt to use extremely low purge gas pressure with a very light weight purge bag could cause premature failure of the bag.

Therefore, the recommended release system will use a bellows which will sense the change in pressure and operate a small valve. The valve will introduce gas under pressure from a small storage vessel (approximately 5 in. long x 1 in. diameter) to expand the flexible metal tubing shown in Fig. 2 and thus release the purge gas.

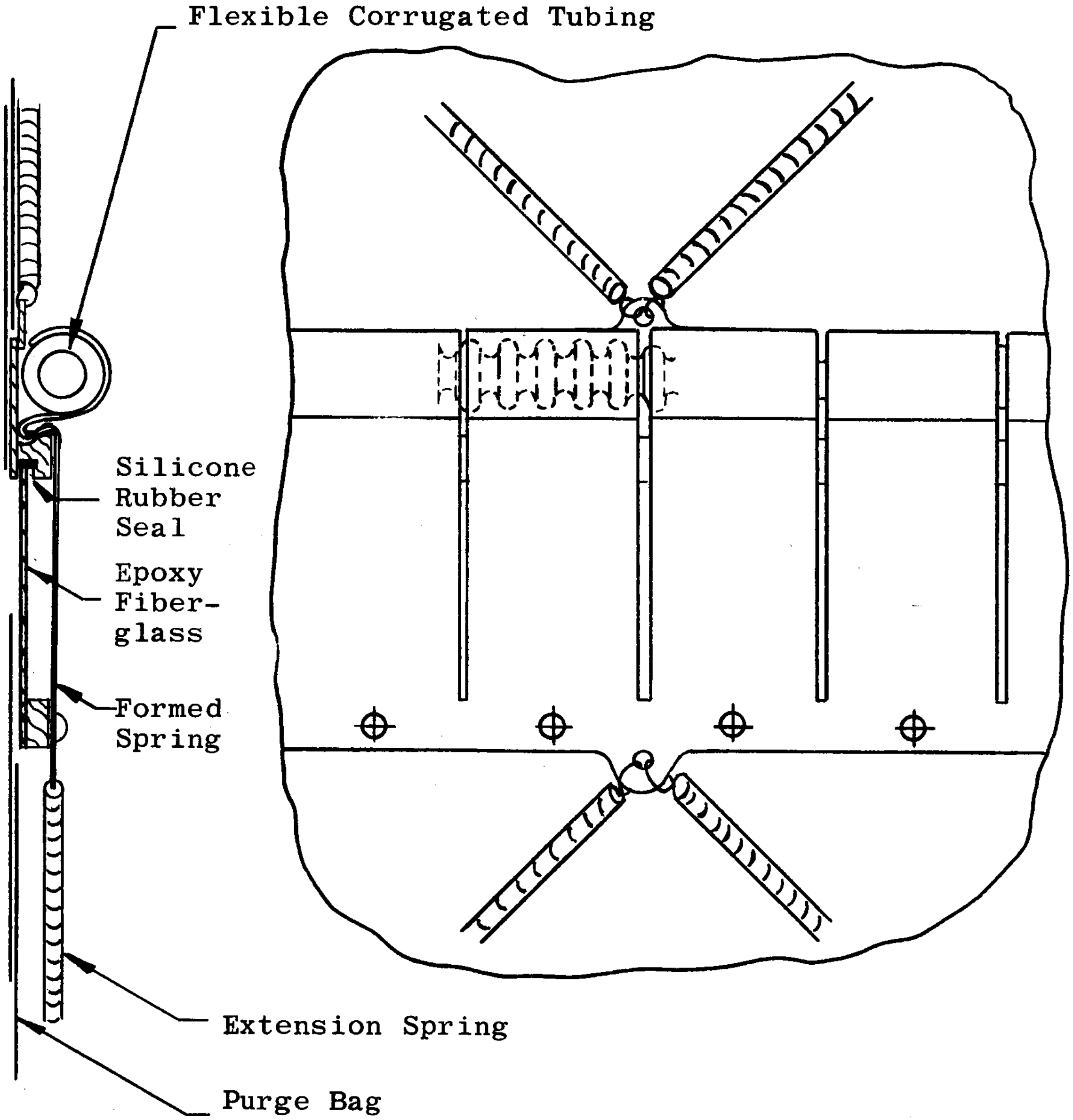
FIGURE I



VIEW AA SHOWN IN FIGURE 2

SCHEMATIC VIEW OF PURGE BAG ASSEMBLY

FIGURE 2



SECTION AA OF FIGURE I

SKETCH OF PURGE BAG RELEASE DEVICE

The release valve and bellows operator are conventional equipment but will require that NASA provide detailed specifications of such variables as vibration accelerations and temperature to a suitable vendor. At least one vendor, Northeast Engineering, Inc., Hamden, Connecticut, has indicated to NRC his ability and interest in developing the small valve required.

Instrumentation Study

The general method and procedure which will be recommended for measuring pressure in the multilayers has been determined. Calculations must still be made to establish physical dimensions for the components of the system. It is expected that the system will consist of small gauge tubulation, a calibrated orifice, a diffusion pumping system and an ionization gauge.

Similarly the general procedures for measuring temperatures in the multilayers have been considered, but detailed recommendations remain to be completed.

ANALYSIS AND RECOMMENDATIONS

Summary Of Heat Leaks

The summary below is a tabulation of results of calculations reported in previous quarterly reports and in the earlier part of this report.

TABLE I

Summary Of Heat Leaks To 105" Vessel

	Btu/hr
Normally through NRC-2	29.1
Along overlapping shingles of NRC-2	15.5
Along 2 titanium alloy struts	6.3
Along 1 titanium rod, up and down	0.3
Two tube penetrations, assumed 36 in. long	6.2
Two tube penetrations, 14 in. long unattached	0.3
Total	57.7

From this, it is apparent that the titanium struts present a significant heat leak to the system. The value for the two 36 in. long tube penetrations is probably high since the insulated length of these will probably be longer than 36 in. when installed.

Inital comparisons show that the heat leak for this system is approximately 1.4 times that calculated for the nitrogen purged 70 in. diameter vessel whereas the vessel area and volume ratios are 1.21 and 1.55 respectively.

Summary Of Weights

The amount of NRC-2 required is approximately 65 pounds for this system. The protective Mylar adds another 11 pounds approximately. The weight of the purge bag has not been calculated yet, but must be added to these values to obtain the total system weight. The NRC-2 weight is nearly 1.5 times that calculated for the nitrogen purged 70 in. diameter vessel.

The weights and heat leaks appear to be consistent with themselves and with the previous work on the 70 in. diameter vessel.

Future Work

The manufacturing drawings of the NRC-2 Superinsulation system, installation templates, and the design drawings of the purge bag will be completed in December, 1965. Recommendations for purge bag sealing techniques will be indicated on the purge bag design drawings. Procedure instructions will be revised to assist in the assembly work.

Some further work remains to complete the recommendations for measuring temperature and pressure within the multilayer system.